Disc tilt detecting device

The invention relates to a device for scanning an optical disc, the disc comprising a pattern of substantially parallel data tracks, the device comprising an optical pick up unit for converging a light beam into a spot on a data track of the pattern, means for moving the spot relative to the pattern, means for determining a radial tracking error signal, the radial tracking error signal indicating a deviation of the spot relative to the data track, and means for detecting a tilt angle between an optical axis of the pick up unit and the optical disc.

The invention also relates to a method and a computer program for detecting a tilt angle of a part of an optical disc, the method comprising the steps of moving a light spot relative to a pattern of substantially parallel data tracks on the optical disc, determining a radial tracking error signal indicating a deviation of the spot relative to a data track and detecting the tilt angle of the part of the optical disc.

The European patent EP 0486613 describes an optical disc player comprising an optical pick up unit (OPU), provided with an objective lens for converging a light beam into a spot on an optical disc. After reflection at the optical disc and passing of the lens, the light beam is detected by a photo detector. The optical disc player also comprises a tracking servo unit for keeping the spot on-track during the reading of data from the disc. The tracking servo radially moves the OPU in accordance with a radial tracking error. The radial tracking error indicates the deviation of the spot relative to a data track on the optical disc. The player also comprises a tilt servo unit for controlling the light beam to be perpendicular to the disc surface, according to a disc tilt signal. For detecting disc tilt the tracking servo is turned off. When an information reading laser beam is in on-track state, i.e. when the spot of the laser beam is on the center of a recording track, a sample and hold circuit samples a radial push pull signal (RPP). The RPP signal is obtained by determining a differential output of two halves of a split photo detector. The obtained RPP signal is a measure for the beam landing error, possibly caused by disc tilt. A beam landing error may also be caused by relative positional division between the objective lens and the photo detector of the optical pick up

unit (OPU), which OPU serves for reading data from the optical disc. The method for detecting disc tilt, described in EP 0486613, assumes a perfect alignment of the objective lens and the photo detector. In this event the beam landing error is regarded to be caused by disc tilt only and the RPP signal is issued as a disc tilt detecting signal.

A drawback of the method for detecting disc tilt, described in EP 0486613 is that a detected beam landing error, caused by misalignment of optical parts of the pick up unit will be misinterpreted as a disc tilt error. This misinterpretation may result in an offset in the disc tilt signal and an incorrect adjustment by the tilt servo unit. This may lead to a problematic reading of data from the disc.

It is an object of the invention to provide a device for scanning an optical disc with means for detecting disc tilt, which means is arranged for accurately detecting a disc tilt error signal by reducing the offset in the disc tilt error signal.

With the device of the invention this object is realized in that that the means for determining the radial tracking error signal is arranged for determining a periodic signal from the radial tracking error signal while the spot is radially moving across the pattern, a period of the periodic signal corresponding to a pitch of the data tracks, and in that the means for detecting the tilt angle is arranged for detecting an asymmetry in the periodic signal during the period.

One period in the periodic signal corresponds to the pitch of the data tracks. The signal of the period is symmetric when no disc tilt occurs and is repeated for every track. When disc tilt occurs the signal during the period becomes asymmetric. Disc tilt is detected by detection of asymmetry in the signal during the period

With the invention, in contrast with the prior art, beam landing errors can be distinguished from disc tilt errors. Beam landing errors may, depending on the type of radial tracking error signal, cause a shift of the periodic signal, but do not substantially affect the symmetry of the signal. Detection of asymmetry in the periodic signal is therefore an adequate method for determining a disc tilt error signal and reduces the possibility that an offset occurs in the disc tilt error signal, for example, as a result of a beam landing error.

The invention relies on the insight that the periodic signal, obtained from the radial tracking error signal while moving across the pattern, is asymmetrically deformed when disc tilt occurs. The deformation of the periodic signal is caused by an asymmetry in the spot on the pattern of data tracks. The upper part of Figure 1a shows an intensity of the

spot as a function of radial position in the event that there is no disc tilt. The lower part of Figure 1a shows an intensity contour of the spot. In this event the spot is symmetric. The effect of disc tilt on the spot on the pattern of data tracks is shown in Figure 1b. The upper part of Figure 1b shows an intensity of the spot as a function of radial position in the event that disc tilt occurs. In Figure 1b there is an extra lobe at one side of the spot. The lower part of Figure 1b shows an intensity contour of the spot. In this event the spot is asymmetric because of the lobe at one side of the spot.

In one embodiment the means for detecting the tilt angle is arranged for integrating the periodic signal over an integer number of periods. The integer number being greater than or equal to one. In general, when no disc tilt or beam landing error occurs, the radial tracking error signal is zero when the spot is in on-track position. Regardless of the type of radial tracking error signal, the value of the signal represents a certain amount of radial deviation and the sign of the signal represents the direction of the deviation. Hence, a part of a period of the periodic signal is below zero and another part is above zero. When no disc tilt occurs, the periodic signal is symmetric and the integral over a whole period of the signal is zero. When disc tilt occurs, the periodic signal is asymmetric and the integral over the whole period of the signal is not zero. Evidently, also the integral over a plurality of whole periods is not zero. The greater the integral, the greater the asymmetry.

In an embodiment the means for detecting the tilt angle is arranged for determining a shift of a zero crossing of the periodic signal. When no disc tilt occurs and the spot center is located at the center of a track, the radial tracking error signal is zero. When the spot is located halfway between two tracks, the radial tracking error signal is also zero. The distance between two zero crossings equals half the track pitch (the track pitch of a DVD is about 0.37 μm). When disc tilt occurs, the periodic signal becomes asymmetric. As a symptom of the asymmetry the zero crossings in the periodic signal are shifted. When no disc tilt occurs the distances between subsequent zero crossings are equal, even in the event of a beam landing error. When disc tilt does occur the distances are not equal. A shift of the zero crossings may be detected by comparing the distances between subsequent zero crossings.

An embodiment of the device according to the invention comprises means for memorizing detected tilt angles for positions on the disc and means for creating a tilt map of the optical disc depending on memorized tilt angles. The tilt map may be used later during scanning of the disc for estimating tilt angles for positions of which the tilt angle is not measured. A correction, depending on the location of the spot on the disc, may then be applied to the scanning process for neutralizing possible negative effects of the disc tilt, such

as problems with reading data from the disc. A device may further comprise a memory for storing models of tilted discs, means for comparing the memorized tilt angles to the models for selecting an appropriate model, which model resembles the disc and wherein the means for creating the tilt map are arranged for creating a tilt map depending on the memorized tilt angles and the appropriate model. Based on detected tilt angles at a few radial and angular positions on the disc and the model, tilt angles may be calculated for all positions on the disc.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

In the drawings:

Figure 1a shows an intensity function and an intensity contour of a spot on a flat disk;

Figure 1b shows an intensity function and an intensity contour of a spot on a tilted disk;

Figure 2 shows a block diagram of a device according to the invention;

Figure 3 shows one period of a periodic radial tracking error signal (RPP) for a flat disc and for a tilted disc;

Figure 4 shows one period of a periodic radial tracking error signal (DTD) for a flat disc and for a tilted disc;

Figure 5 shows a correlation between disc tilt and an integral over a period of the periodic radial tracking error signal (RPP);

Figure 6 shows a correlation between disc tilt and an integral over a period of the periodic radial tracking error signal (DTD);

Figure 7 shows a block diagram of a device according to the invention, comprising means for creating a tilt map;

Figure 8 shows a block diagram of a device according to the invention, using tilt models for creating a tilt map;

Figure 9 shows an exaggerated example of a non flat, dish shaped disc;

Figure 10 shows an exaggerated example of a non flat, saddle shaped disc; and

Figure 11 shows a flow diagram of a preferred disc tilt detection procedure according to the invention.

In the diagrams below, similar references designate similar elements;

Figure 2 shows a block diagram of a device 201 according to the invention. An optical disc 202 is inserted into the device 201 for being scanned by the device 201. The optical disc 202 comprises a pattern of substantially parallel data tracks 203. The optical disc may for example be a CD or a DVD. The scanning may, for example, be performed to read data from or write data onto the optical disc 202. The scanning may also be performed for testing the quality of the optical disc 202. The device 201 comprises an optical pick up unit (OPU) 204 for converging a light beam 206 into a spot 208 on a data track of the pattern. Means 209 for moving the spot 208 relative to the pattern of data tracks 203 are provided. The OPU 204 comprises an objective lens 207 for converging the light beam 206 and a photo detector 205 for detecting the light beam 206 after reflection at the optical disc 202. The signal from the photo detector 205 is processed by means 210 for determining a radial tracking error signal and means 211 for determining a tilt angle. The tilt angle 214 may be defined as the angle between a normal 213 of the optical disc 202 and the optical axis of the pick up unit 204 or a line 212 parallel to the optical axis.

The means 209 for moving the spot 208 relative to the pattern of data tracks 203 may be realized in an actuator for moving the OPU 204 radially over the tracks. The means 209 for moving the spot 208 may also be realized in a mechanism for disc rotation. For example a spindle motor may be used for rotating the disc. In practice the center of rotation of the disc 202 does not exactly coincide with the center of the pattern of data tracks 203. When the OPU 204 is in a fixed position and the disc is rotating, several tracks will pass the light spot 208. A combination of OPU movement and disc rotation may also be used for moving the spot 208 relative to the pattern 203.

Different types of radial tracking error signals are known. Often used are Radial Push Pull (RPP) signals, Differential Phase Detection (DPD) and Differential Time Detection (DTD2, DTD4). Some types of radial tracking error signal require a split photo detector. The photo detector 205 may be divided in two or more parts, depending on the type of radial tracking error signal used by the device. Alternatively, two or more detectors may be used.

Two periodic signals, obtained from different types of radial tracking error signals, are shown in Figure 3 and Figure 4. In Figure 3 A Radial Push Pull (RPP) signal is shown as a function of the radial deviation. This signal may be obtained by sampling the RPP signal while the spot is moving across the pattern of data tracks. Thus a periodic RPP signal is obtained as a function of time. When it is assumed that the spot moves across the pattern

with constant velocity, which is approximately true for one period of the periodic signal, the signal may be regarded to be a function of the deviation. For RPP a detector 205 with two halves is used. In this event a split detector 205 is realized in that the outputs A and C are summed as are the outputs B and D. The RPP signal equals the output difference of the two detector halves, divided by the total detector output. The RPP signal is often used for radial tracking and can easily be obtained by a person skilled in the art. A symmetric dotted line 31 denotes the RPP signal when no beam landing error or disc tilt occurs. In the event of a beam landing error but no disc tilt, the RPP signal would also be a symmetric signal. A solid line 32 denotes the RPP signal when a certain amount of disc tilt occurs. In the event of disc tilt, the RPP signal is not symmetric. The means 211 for detecting disc tilt in device 201 is arranged for detecting an asymmetry in the periodic signal 32 as described later on.

In Figure 4 A Differential Time Detection (DTD) signal is shown as a function of the radial deviation. For obtaining a DTD signal, the outputs of four detector parts, A, B, C, and D are acquired and processed while the spot moves along a data track. When the spot center deviates from the track center, not all detector parts 205A-205D will detect an information pit on the data track at the same time. For determining a DTD signal the time differences between zero crossings of the signals from four detector parts 205A-205D are used. The DTD signal is often used for radial tracking and can easily be obtained by a person skilled in the art. An advantage of the DTD signal is that it is hardly affected by beam landing errors or defocus. The periodic DTD signal may be obtained in a way similar to the way for obtaining the periodic RPP signal, by determining a DTD signal while the spot moves radially across the track pattern. In Figure 4 a symmetric dotted line 41 denotes a DTD signal when no disc tilt occurs. A solid line 42 denotes a DTD signal when disc tilt does occur. In the event of disc tilt, the DTD signal is not symmetric. The means 211 for detecting disc tilt in device 201 is arranged for detecting an asymmetry in the periodic signal 42 as described hereafter.

Asymmetry may for example be detected by integrating the periodic signal over n periods ($n \geq 1$). Integration may for example be realized by including a low pass filter in the tilt angle detection means 211. Examples of the relation between disc tilt and the integral of the periodic signal are shown in Figure 5 and Figure 6. Both figures illustrate that the integral over the radial tracking error signal is a good indicator of disc tilt. The more disc tilt occurs, the greater the integral becomes. The sign of the integral denotes the direction of the disc tilt. Figure 5 shows the relation between the integral over an integer number of

periods of a RPP signal. Figure 6 shows the relation between the integral over an integer number of periods of a DTD signal.

Asymmetry may also be detected by examining the zero crossings in the periodic signal. When no disc tilt occurs and the spot center is located at the center of a track, the radial tracking error signal is zero. When the spot is located halfway between two tracks, the radial tracking error signal is also zero. The distance between two zero crossings equals half the track pitch (the track pitch of a DVD is about 0.37 · m). When disc tilt occurs, the periodic signal becomes asymmetric. As a symptom of the asymmetry the zero crossings in the periodic signal are shifted. A shift of the zero crossings may be detected by comparing the distances between subsequent zero crossings. When for example, a first distance between the zero crossing representing a track center and the zero crossing representing the nearest halfway point between two tracks at the left of the track and a second distance between the track center and the nearest halfway point at the right are not equal, an asymmetry exists. The comparing of the two distances may be done by subtracting or dividing the two distances.

The device shown in Figure 7 comprises all features of the device shown in Figure 2. The device further comprises a memory 701 for memorizing detected tilt angles for positions on the disc. The tilt angles are detected by means 211 for detecting disc tilt as described above, while the spot 208 moves radially across the pattern of data tracks 203. The device also comprises means 702 for creating a tilt map of the optical disc depending on memorized tilt angles. The tilt map comprises the tilt angles of the positions on the disc of which the tilt angle is detected and also comprises estimated tilt angles for other positions on the disc 202. The estimated tilt angles are calculated by means 702 depending on the detected tilt angles, for example, by averaging the detected tilt angles at one or more nearby positions. The means 702 for creating a tilt map may, for example, be a dedicated processor or a processor controlled by software. The tilt map may be used during data recording or retrieval, for neutralizing possible negative effects of disc tilt. Several methods for correcting disc tilt, such as tilting the disc 202 or the objective lens 207, or using signal processing for correcting a disturbed data signal are well known to persons skilled in the art.

Figure 8 shows a further embodiment of the device shown in Figure 7 and further comprises a memory 703 for storing models of tilted discs and means 704 for comparing the memorized tilt angles in memory 701 to the models. One example of a model describes a flat disc 202, which is tilted with respect to a surface normal to the optical axis of the OPU 204. In this model, all positions on the disc have the same tilt angle. Disc tilt also occurs when a disc 202 is not flat. A disc 202 may for example be dish shaped or saddle

shaped due to manufacture errors, or bent due to mistreatment by a user. The memory 703 comprises several models for different types of non flat discs. Means 704 compares the memorized tilt angles to the stored models. The model that best fits the memorized tilt angles is used by means 702 for creating a detailed tilt map of the disc 202. The tilt map may be stored on memory 703 or another memory, together with information which uniquely identifies the disc 202. When the tilt map is stored, it can later be retrieved when the disc is used again and the scanning may start without first having to perform the tilt map creating procedure.

Figure 9 and Figure 10 show examples of exaggerated models of non flat discs. Figure 9 shows an exaggerated example 91 of a dish shaped disc. From a few known tilt angles for points with different radial positions on the disc, a complete tilt map can be created by means 702, using the model of the dish shaped disc. Figure 10 shows an exaggerated example 101 of a saddle shaped disc. From a few known tilt angles for points with different radial and angular positions on the disc, a complete tilt map can be created by means 702, using the model of the saddle shaped disc.

Figure 11 shows a flow diagram of a preferred disc tilt detection procedure for execution in a playback or recorder device for optical discs. In *insertion* step 111 a disc is inserted in the device and a focus servo and a tracking servo are switched on. The focus servo serves for detecting and correcting the spot position in the vertical direction. The tracking servo serves for detecting and correcting the spot position in the radial direction for keeping the spot on track while scanning the disc. In *read attempt* step 112 an attempt is made to read data from the disc. If the attempt is successful, the scanning of the disc may start in *scanning* step 113. The scanning may serve for reading data from or writing data onto the data tracks of the disc. If the attempt is not successful, a jitter is analyzed in an optional *jitter analysis* step 114. Analyzing jitter is a well known method for identifying the origin of problems with reading data from a disc. When it is concluded from the jitter analysis that disc tilt is not the cause of the reading problems, an error message may be provided in *error* step 117 or other correction methods may be applied. When disc tilt turns out to be the problem or when the optional step 114 is not performed, a disc tilt measurement may be started in *first tilt measure* step 115. For the disc tilt measurement first the tracking servo is switched off and a spindle motor is switched on for rotating the disc. While the disc is rotating and the OPU is in a stationary position, several tracks pass the light spot. While the data tracks move under the light spot, the periodic radial tracking error signal is obtained and disc tilt is determined. If the disc tilt detection is successful, the tilt detection is repeated several times in *first tilt*

mapping step 116, with the OPU in different radial positions. Then a tilt map is created depending on memorized tilt angles, possibly using disc tilt models as described above. If the disc tilt detection in step 115 is not successful, a second attempt for detecting disc tilt will be made in step *second tilt measure* 118. In this event, the disc rotation is stopped and the OPU is radially moved across the pattern of data tracks. While the light spot moves over the data tracks and the periodic radial tracking error signal is obtained, disc tilt is determined. If the disc tilt detection is successful, the tilt detection is repeated several times in *second tilt mapping* step 119, with the disc in different angular positions. Then a tilt map is created depending on memorized tilt angles, possibly using disc tilt models as described above. If the disc tilt detection in step 118 is not successful, an error message may be provided in step 117 or other correction methods may be applied. After successfully creating a tilt map in step 116 or step 119, the scanning of the disc may start in step 113 and the tilt map is used for correcting for disc tilt during the scanning of the disc.

It is noted that the disc described above may also be a record carrier with a non circular shape, such as a rectangular or triangular card. When, for example, using a rectangular shaped card, moving a spot 'radially across the pattern of substantially parallel data tracks' means moving the spot over the pattern perpendicular to the data tracks. For rectangular cards disc rotation is a possible way for moving the pattern of data tracks relative to a stationary or moving spot, but may not be very convenient. When using rectangular cards disc rotation is preferably substituted by disc translation. A Radial Push Pull signal may still be determined, although a Perpendicular Push Pull signal might be a better term for describing the tracking error signal.

It is noted that in this document the word 'comprising' does not exclude the presence of other elements or steps than those listed and the word 'a' or 'an' preceding an element does not exclude the presence of a plurality of such elements, that any reference signs do not limit the scope of the claims, that the invention may be implemented by means of both hardware and software, and that several 'means' may be represented by the same item of hardware. Further, the scope of the invention is not limited to the embodiments, and the invention lies in each and every novel feature or combination of features described above.